# HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

(Contract No. DE-2600BC15128)

# DELIVERABLE 2.1.2
# PRODUCTION ANALYSIS: CHEROKEE AND BUG FIELDS, SAN JUAN COUNTY, UTAH

*Submitted by*

**Utah Geological Survey**
Salt Lake City, Utah 84114
December 2003

Contracting Officer's Representative

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# DISCLAIMER

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***Thomas C. Chidsey, Jr., Principal Investigator/Program Manager, Utah Geological Survey***

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# INTRODUCTION

Over 400 million barrels (64 million $m^3$) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation in the Paradox Basin, Utah and Colorado. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million $m^3$) of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short productive life (primary), and hence premature abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field. However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million $m^3$) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

# GEOLOGIC SETTING

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

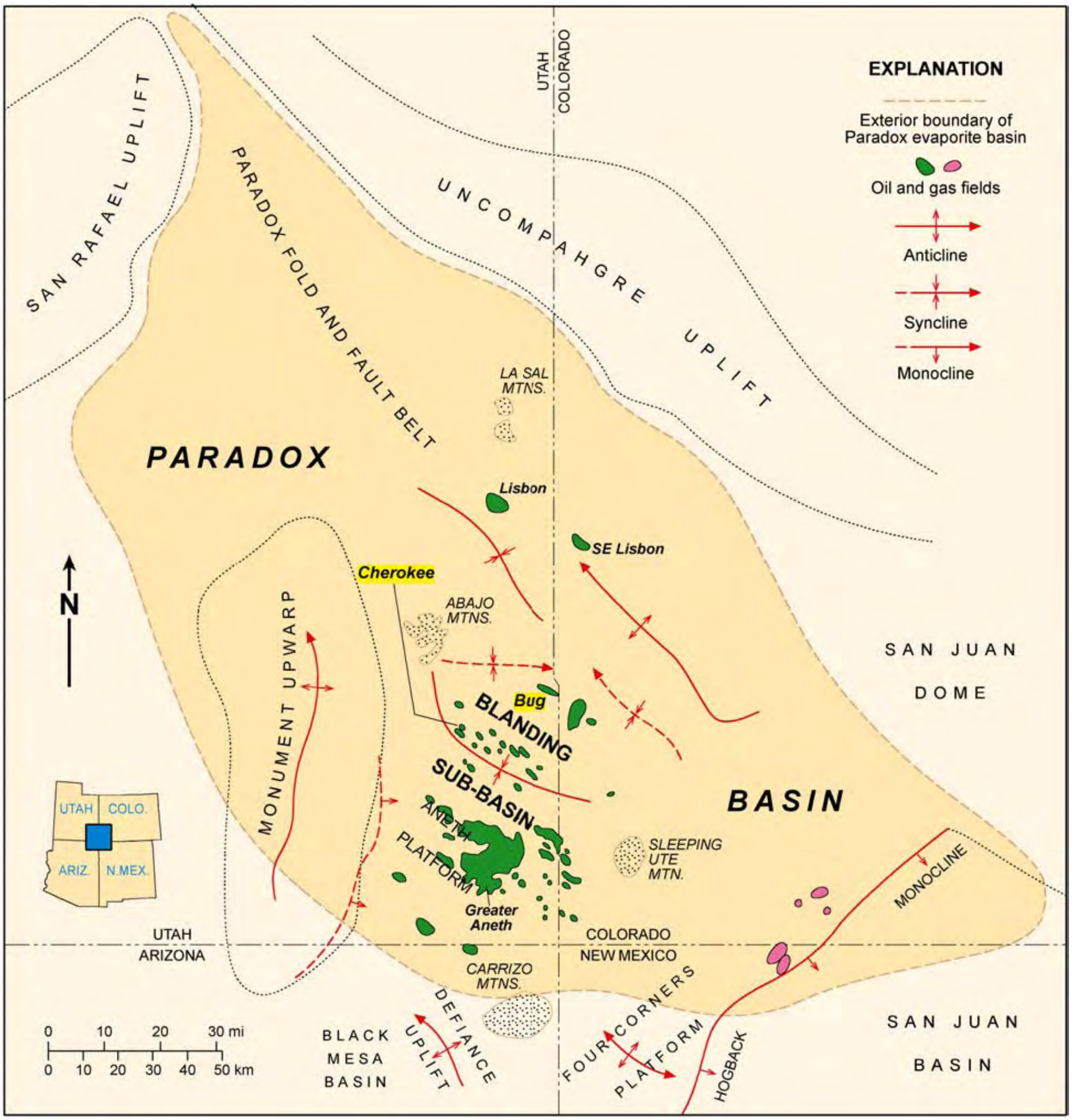



***Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).***

The Paradox Basin can generally be divided into two areas: the Paradox fold and fault belt in the north, and the Blanding sub-basin in the south-southwest (figure 1). Most oil production comes from the Blanding sub-basin. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996). The relatively undeformed Blanding sub-basin developed on a shallow-marine shelf which locally contained algal-mound and other carbonate buildups in a subtropical climate.

The two main producing zones of the Paradox Formation are informally named the Ismay and the Desert Creek (figure 2). The Ismay zone is dominantly limestone comprising equant buildups of phylloid-algal material with locally variable small-scale subfacies (figure 3A) and capped by anhydrite. The Ismay produces oil from fields in the southern Blanding sub-basin (figure 4). The Desert Creek zone is dominantly dolomite comprising regional nearshore shoreline trends with highly aligned, linear facies tracts (figure 3B). The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 4). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

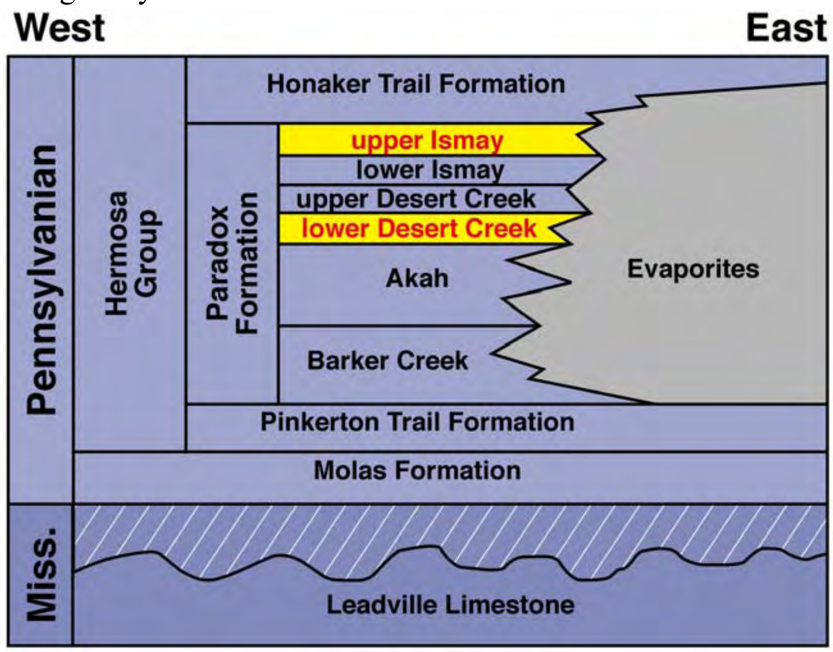



***Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the Ismay and Desert Creek zones productive in the case-study fields described in this report are highlighted.***

## CASE-STUDY FIELDS

Two Utah fields were selected for local-scale evaluation and geological characterization: Cherokee in the Ismay trend and Bug in the Desert Creek trend (figure 4). This evaluation included data collection such as completion and production analysis from wells in these fields as summarized in this report.

This geological characterization focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within the fields. From these evaluations, untested or under-produced compartments can be identified as targets for horizontal drilling. The models resulting from the geological and reservoir characterization of these fields can be applied to similar fields in the basin (and other basins as well) where data might be limited.

### Cherokee Field

Cherokee field (figure 4) is a phylloid-algal buildup capped by anhydrite that produces from porous algal limestone and dolomite in the upper Ismay zone. The net reservoir thickness is 27 feet (8.2 m), which extends over a 320-acre (130 ha) area. Porosity averages 12 percent with 8 millidarcies (md) of permeability in vuggy and intercrystalline pore systems. Water saturation is 38.1 percent (Crawley-Stewart and Riley, 1993).

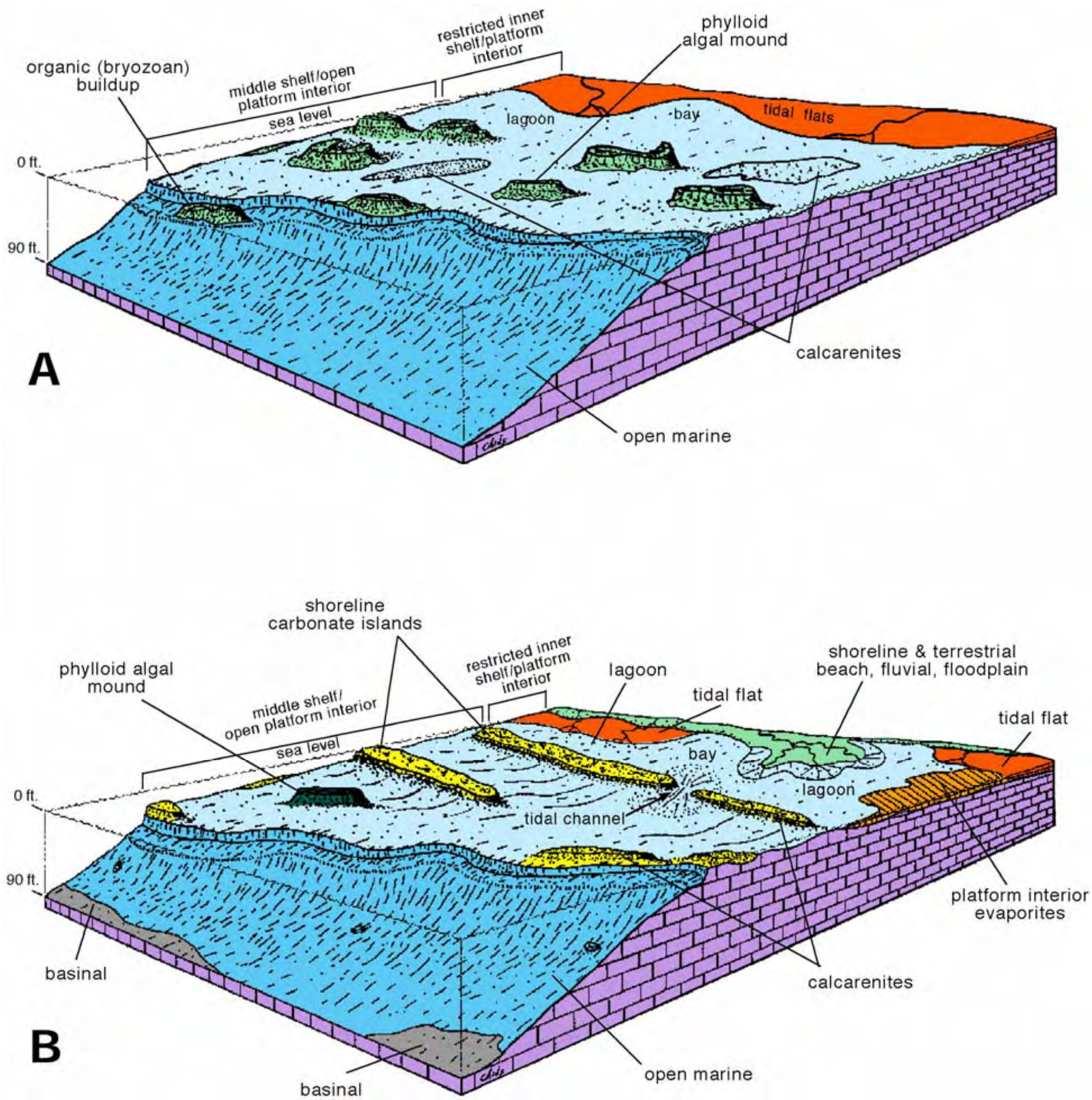



***Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.***

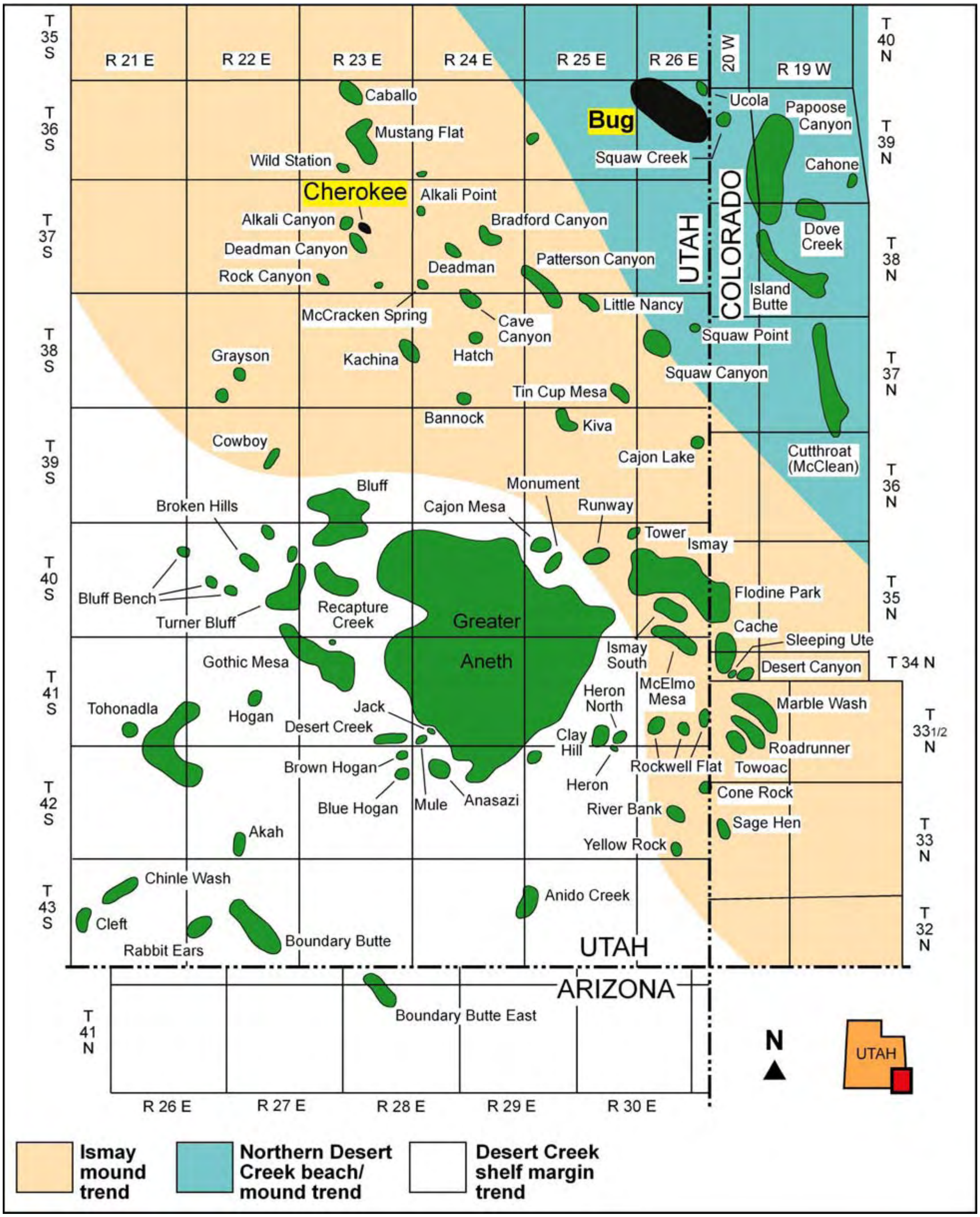



*Figure 4. Map showing the project study area and fields (case-study fields in black) within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.*

Cherokee field was discovered in 1987 with the completion of the Meridian Oil Company Cherokee Federal 11-14, NE1/4NW1/4 section 14, T. 37 S., R. 23 E., Salt Lake Base Line and Meridian (SLBL&M); initial potential flow (IPF) was 53 barrels of oil per day (BOPD) (8.4 $m^3$), 990 thousand cubic feet of gas per day (MCFGPD) (28 MCMPD), and 26 barrels of water (4.1 $m^3$). There are currently four producing (or shut-in) wells and two dry holes in the field. The well spacing is 80 acres (32 ha). The present field reservoir pressure is estimated at 150 pounds per square inch (psi) (1,034 Kpa). Cumulative production as of June 1, 2003, was 182,071 barrels of oil (28,949 $m^3$), 3.65 billion cubic feet of gas (BCFG) (0.1 BCMG), and 3,358 barrels of water (534 $m^3$) (Utah Division of Oil, Gas and Mining, 2003). The original estimated primary recovery is 172,000 barrels of oil (27,348 $m^3$) and 3.28 BCFG (0.09 BCMG) (Crawley-Stewart and Riley, 1993). The fact that both these estimates have been surpassed suggests significant additional reserves could remain.

## Bug Field

Bug field (figure 4) is an elongate, northwest-trending carbonate buildup in the lower Desert Creek zone. The producing units vary from porous dolomitized bafflestone to packstone and wackestone. The trapping mechanism is an updip porosity pinchout. The net reservoir thickness is 15 feet (4.6 m) over a 2,600-acre (1,052 ha) area. Porosity averages 11 percent in moldic, vuggy, and intercrystalline networks. Permeability averages 25 to 30 md, but ranges from less than 1 to 500 md. Water saturation is 32 percent (Martin, 1983; Oline, 1996).

Bug field was discovered in 1980 with the completion of the Wexpro Bug No. 1, NE1/SE1/4 section 12, T. 36 S., R. 25 E., SLBL&M, for an IPF of 608 BOPD (96.7 $m^3$), 1,128 MCFGPD (32 MCMPD), and 180 barrels of water (28.6 $m^3$). There are currently eight producing (or shut-in) wells, five abandoned producers, and two dry holes in the field. The well spacing is 160 acres (65 ha). The present reservoir field pressure is 3,550 psi (24,477 Kpa). Cumulative production as of June 1, 2003, was 1,622,2020 barrels of oil (257,901 $m^3$), 4.47 BCFG (0.13 BCMG), and 3,181,448 barrels of water (505,850 $m^3$) (Utah Division of Oil, Gas and Mining, 2003). Estimated primary recovery is 1,600,000 bbls (254,400 $m^3$) of oil and 4 BCFG (0.1 BCMG) (Oline, 1996). Again, since the original reserve estimates have been surpassed and the field is still producing, significant additional reserves likely remain.

# PRODUCTION ANALYSIS

Before reservoir-modeling studies could be conducted for the Cherokee and Bug fields, analyses of production data were required. These data were compiled through two principal tasks: (1) review of existing well-completion data, and (2) determination of production history from monthly production reports available through the Utah Division of Oil, Gas and Mining. This information was merged with geological characterization data and incorporated into the interpretation of reservoir models. Production "sweet spots" and potential candidates, both wells and fields, were identified. Using the results, various horizontal drilling methods and the ultimate recovery can be estimated for Cherokee and Bug fields.

## Well-Test Data Evaluation

Well-test data can provide key insight into the nature of reservoir heterogeneities, and also provide "large-scale" quantitative data on actual reservoir properties and facies from case-study reservoirs. Although a number of well tests have been conducted in all of the target reservoirs, only the IPF well tests were determined to provide quantitative reservoir property information. IPF well tests were graphed and plotted for each well (figures 5 through 8). The graphs include both oil (in BOPD) and gas (in MCFPD) production.

In Cherokee field, the highest IPF was recorded from the Cherokee Federal 22-14 (figures 5 and 6), located on the crest of the structural nose where the upper Ismay zone buildup developed and in the thickest part of the mound facies (figures 9 and 10). The lowest IPF was recorded from the Cherokee Federal 11-14 (figures 5 and 6), located on the structural low and on the thin flank of the mound buildup (figures 9 and 10). Both wells had relatively high gas-to-oil ratios (GOR) in comparison to the other two producing field wells (figure 5) in the southeastern part of the field (figure 6).

In Bug field, the highest IPFs were recorded from the Bug 1, May Bug 2, Bug 9, and Bug 4 wells (figures 7 and 8), located structurally downdip from the updip porosity pinch out that forms the trap, and in the main part of the lower Desert Creek zone carbonate buildup (figures 11 and 12); Bug 9 was tested from the thickest section of the mound. These wells penetrated both the phylloid-algal mound and the shoreline carbonate island facies of the carbonate buildup. The lowest recorded IPFs were from wells closest to the updip porosity pinch out, or downdip near the oil/water contact (figures 7, 8, and 11). These wells penetrated only the phylloid-algal mound facies (figure 12).

## Cumulative Production

Oil and gas production from Cherokee field has shown a steady decline since peaking in the late 1980s (figure 13). Cumulative production was graphed and plotted for each well (figures 14 through 17). The graphs include both oil and gas production. In Cherokee field, the largest volume of oil has been produced from the Cherokee Federal 33-14, while the highest volume of gas has been produced from the Cherokee Federal 22-14 (figures 14 and 15). Both wells are located on the crest of the structural nose and in the thickest part of the mound facies (figures 9 and 10). The Cherokee Federal 22-14 is slightly higher structurally than the Cherokee Federal 33-14, possibly accounting for the significantly greater volume of gas production. These wells penetrated both the phylloid-algal mound and the crinoid/fusulinid-bearing carbonate sand facies of the carbonate buildup (figure 10). The Cherokee Federal 33-14 may have encountered a significantly thicker section of microporosity and microfractures than other wells, resulting in greater oil production. Microporosity is present in cores from both the Cherokee Federal 33-14 and Cherokee Federal 22-14 (figure 16). This unique pore type represents the greatest hydrocarbon storage capacity and potential horizontal drilling target in the field. The lowest volumes of hydrocarbon production are from wells on both the structural and mound flanks. These wells are likely close to the oil/water contact (its exact elevation is unknown) and have penetrated only the phylloid-algal mound buildup.

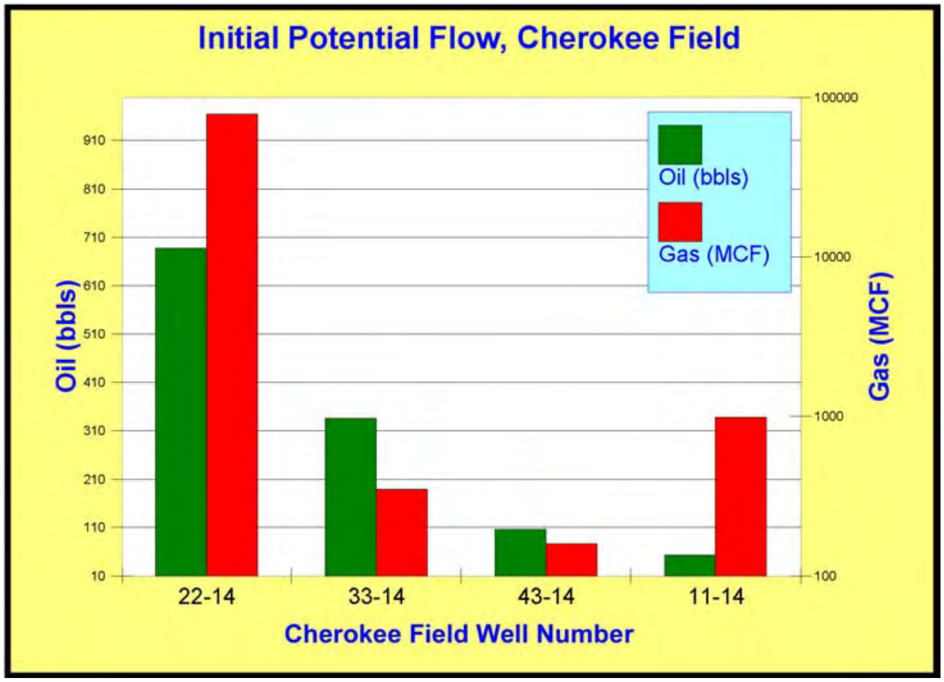



*Figure 5. Initial potential flow of oil and gas, from upper Ismay producing wells, in Cherokee field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

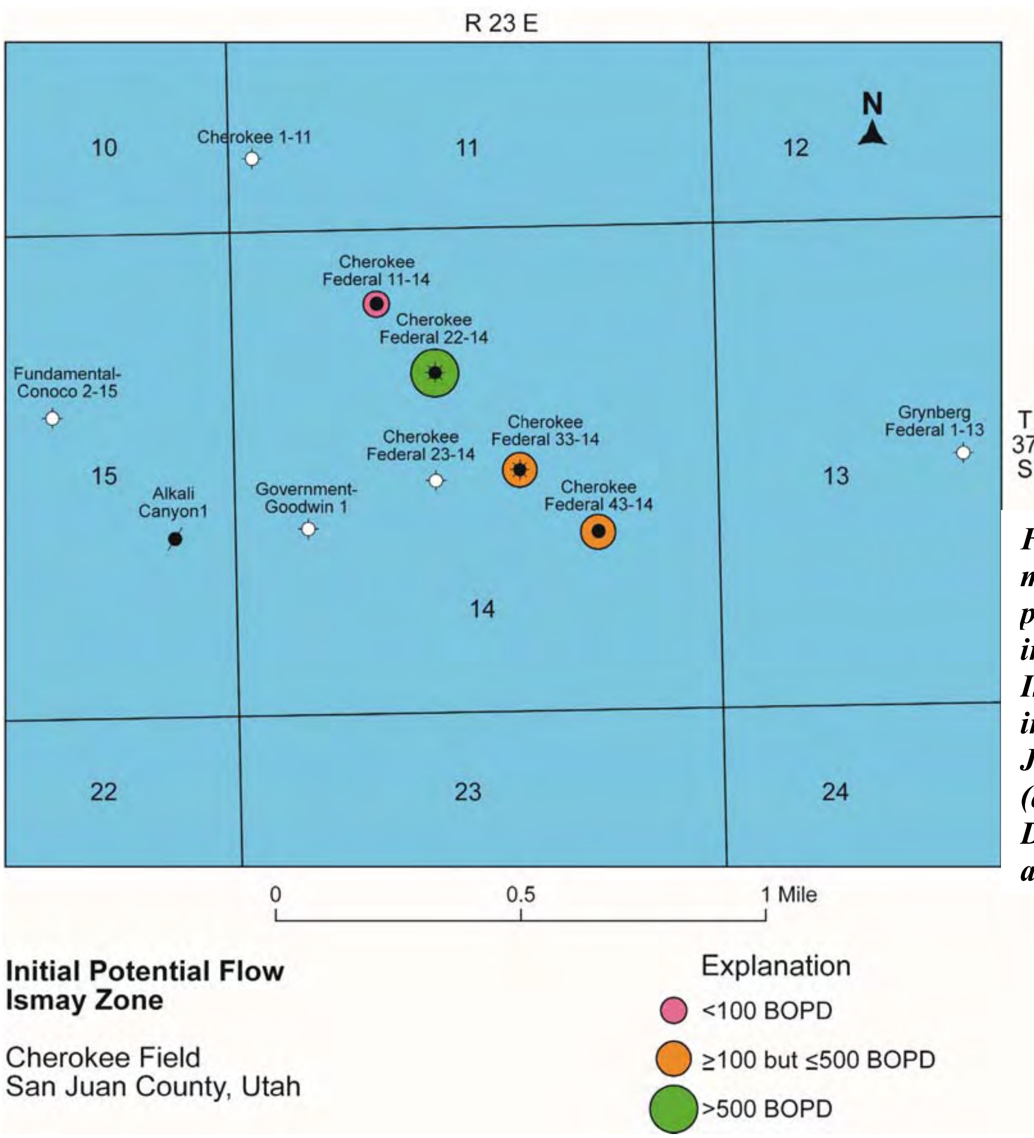



*Figure 6. Bubble map of initial potential flow, of oil in BOPD, from upper Ismay producing wells in Cherokee field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

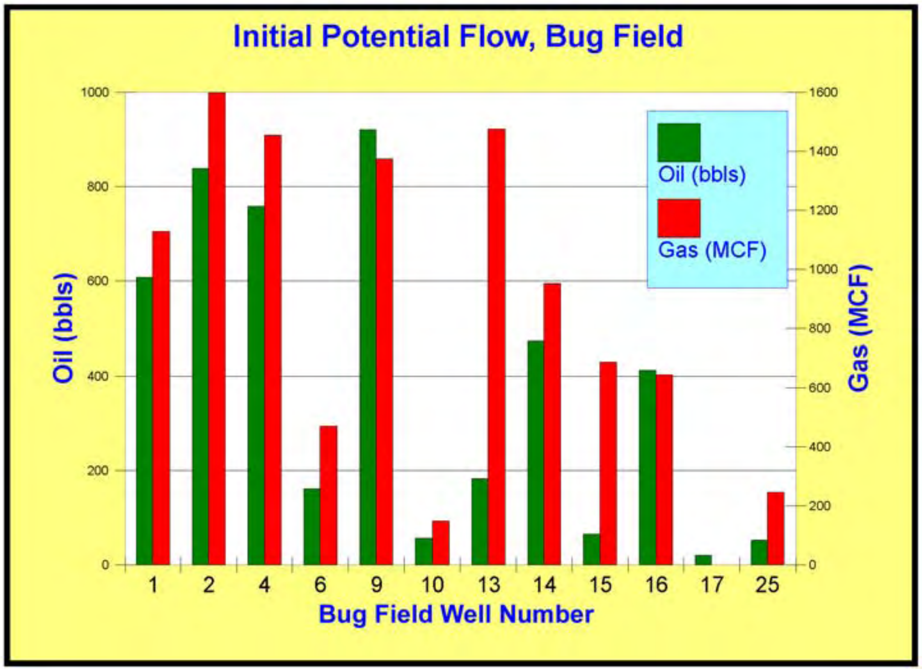



*Figure 7. Initial potential flow of oil and gas, from lower Desert Creek producing wells, in Bug field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

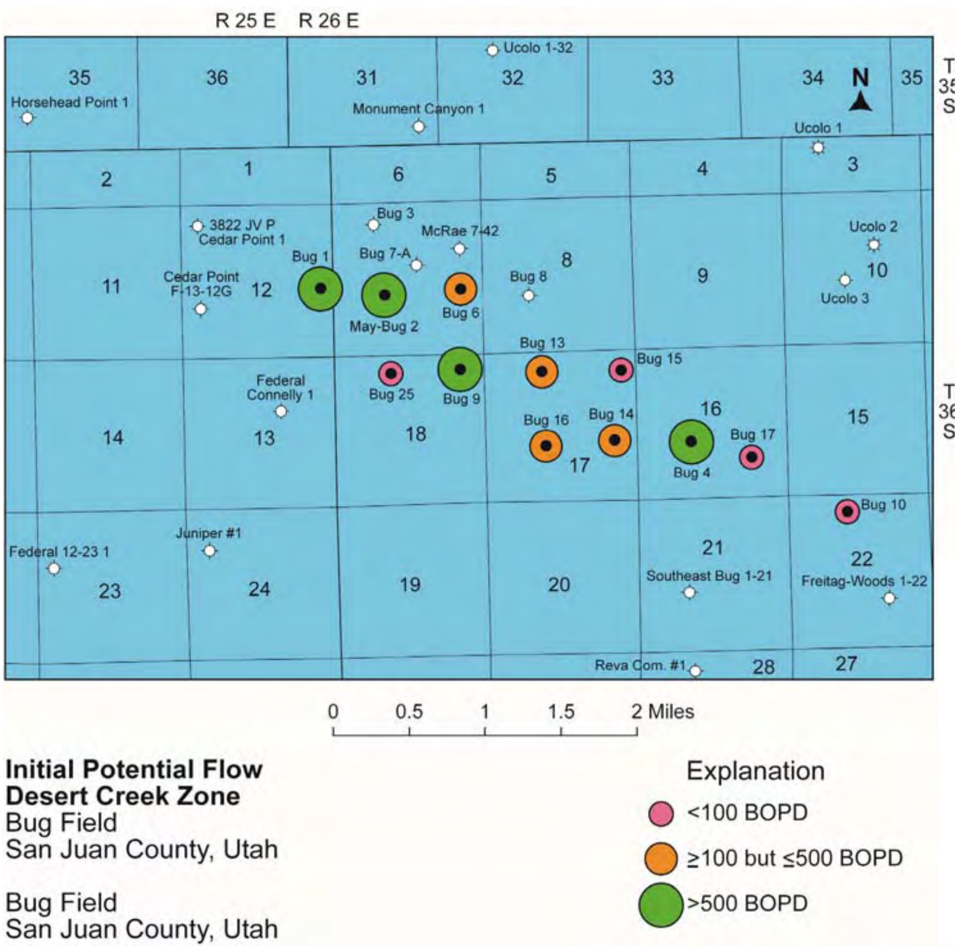



*Figure 8. Bubble map of initial potential flow, of oil in BOPD, from lower Desert Creek producing wells in Bug field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

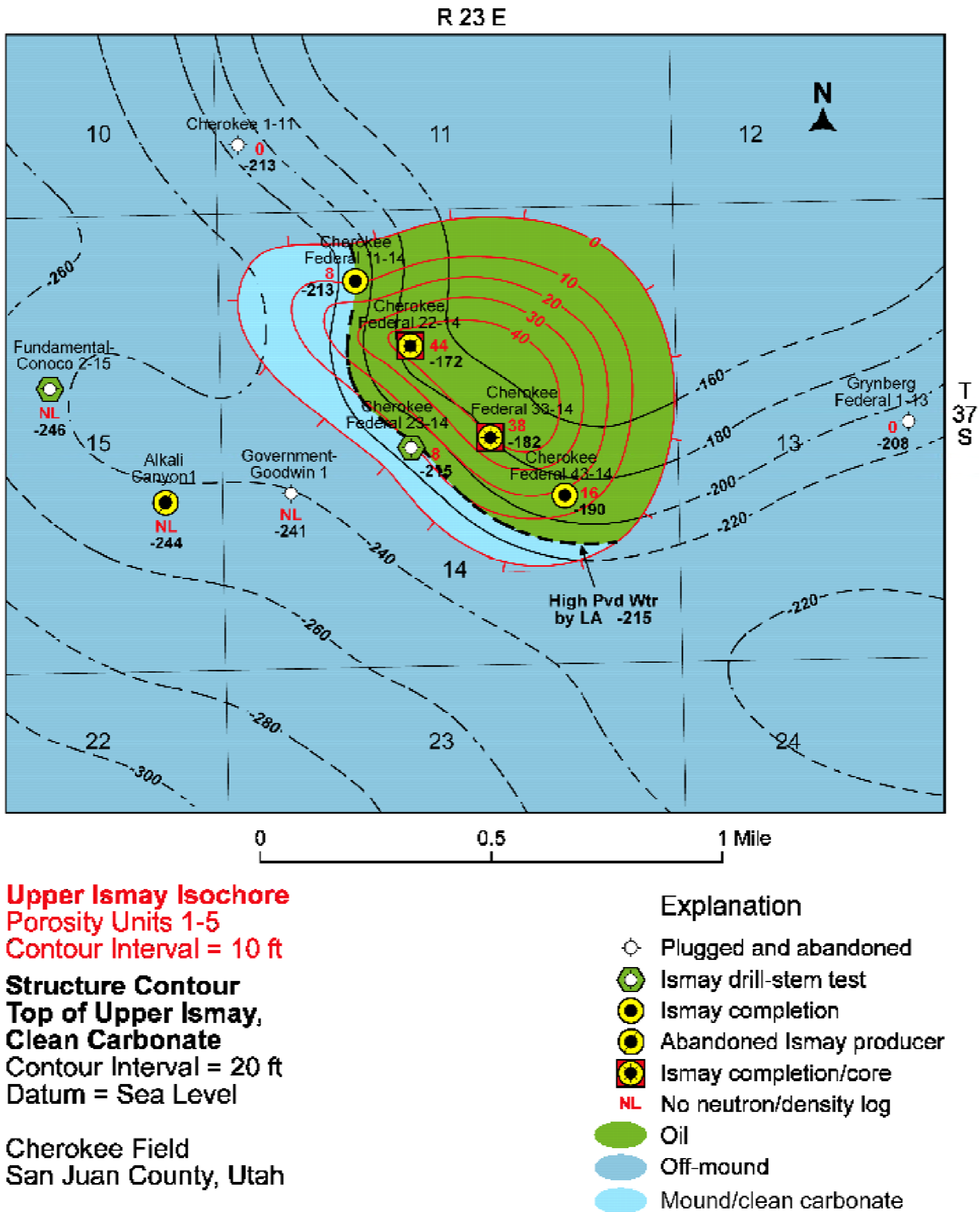



*Figure 9. Map of combined top of "clean carbonate" structure and isochore of porosity units 1 through 5, upper Ismay zone, Cherokee field, San Juan County, Utah.*

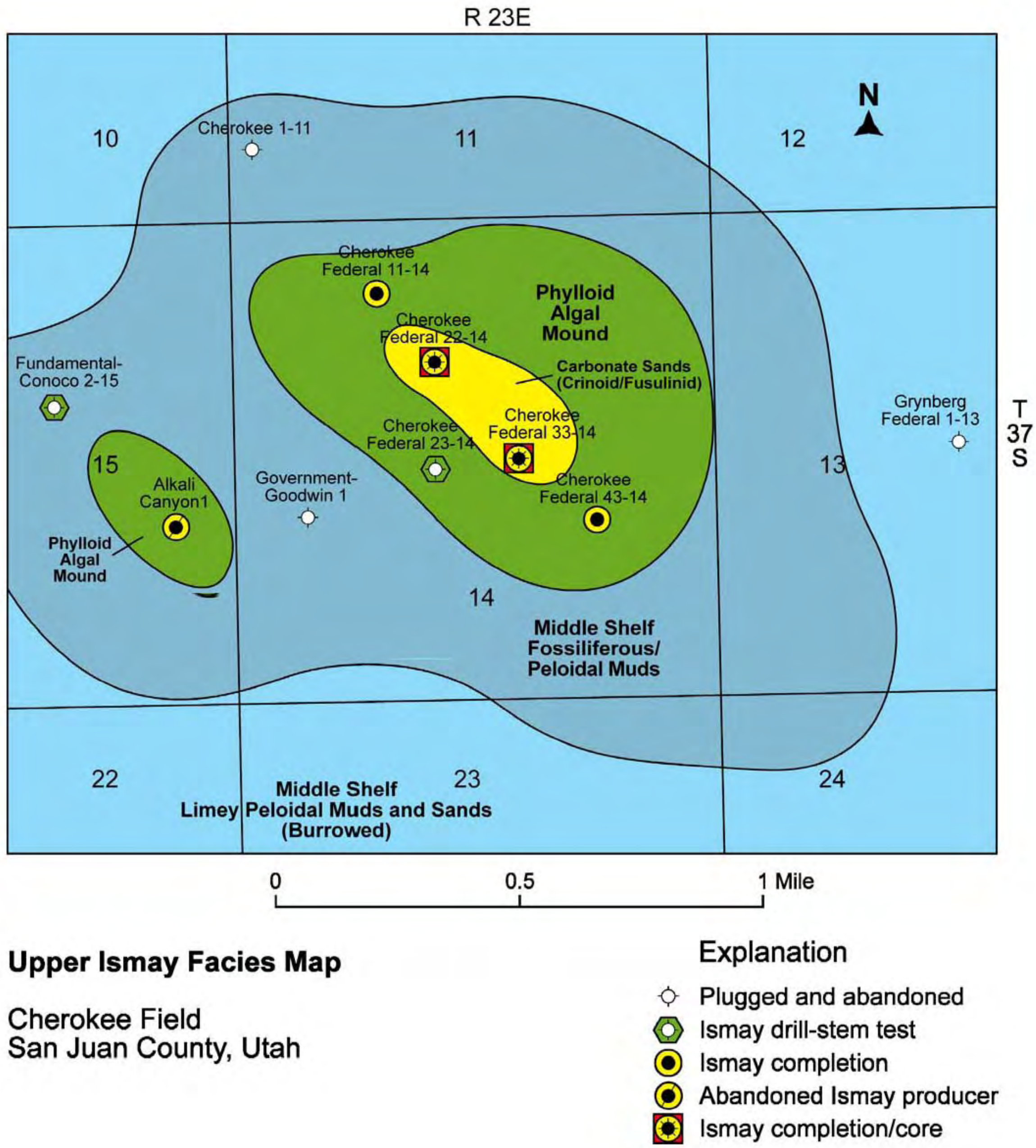
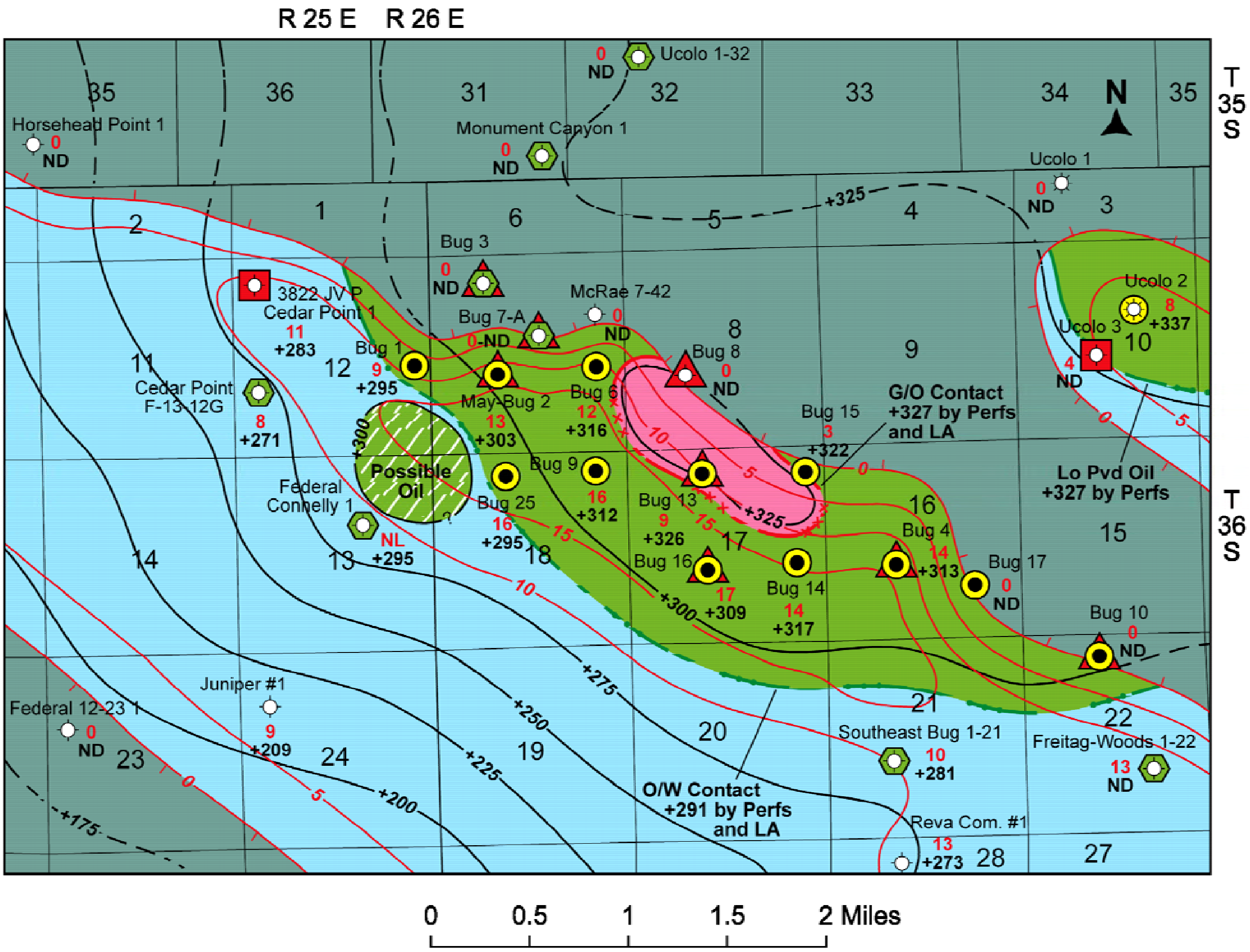



*Figure 10. Upper Ismay zone facies map, Cherokee field, San Juan County, Utah.*




**Isochore**
**Lower Desert Creek Mound**
Contour Interval = 5 ft
Porosity > 6%

**Structure Contour**
**Top of Lower Desert Creek Mound**
Contour Interval = 25 ft
Datum = Sea Level

Bug Field
San Juan County, Utah

**Explanation**
- Plugged and abandoned
- Producing gas
- Desert Creek drill-stem test
- Desert Creek completion
- Desert Creek completion attempt
- Desert Creek core
- NL No neutron/density log
- ND No data
- Oil/water contact
- Gas/oil contact
- Gas
- Oil
- Off-mound
- Mound/clean carbonate

*Figure 11. Map of combined top of structure and isochore of lower Desert Creek zone mound, Bug field, San Juan County, Utah.*

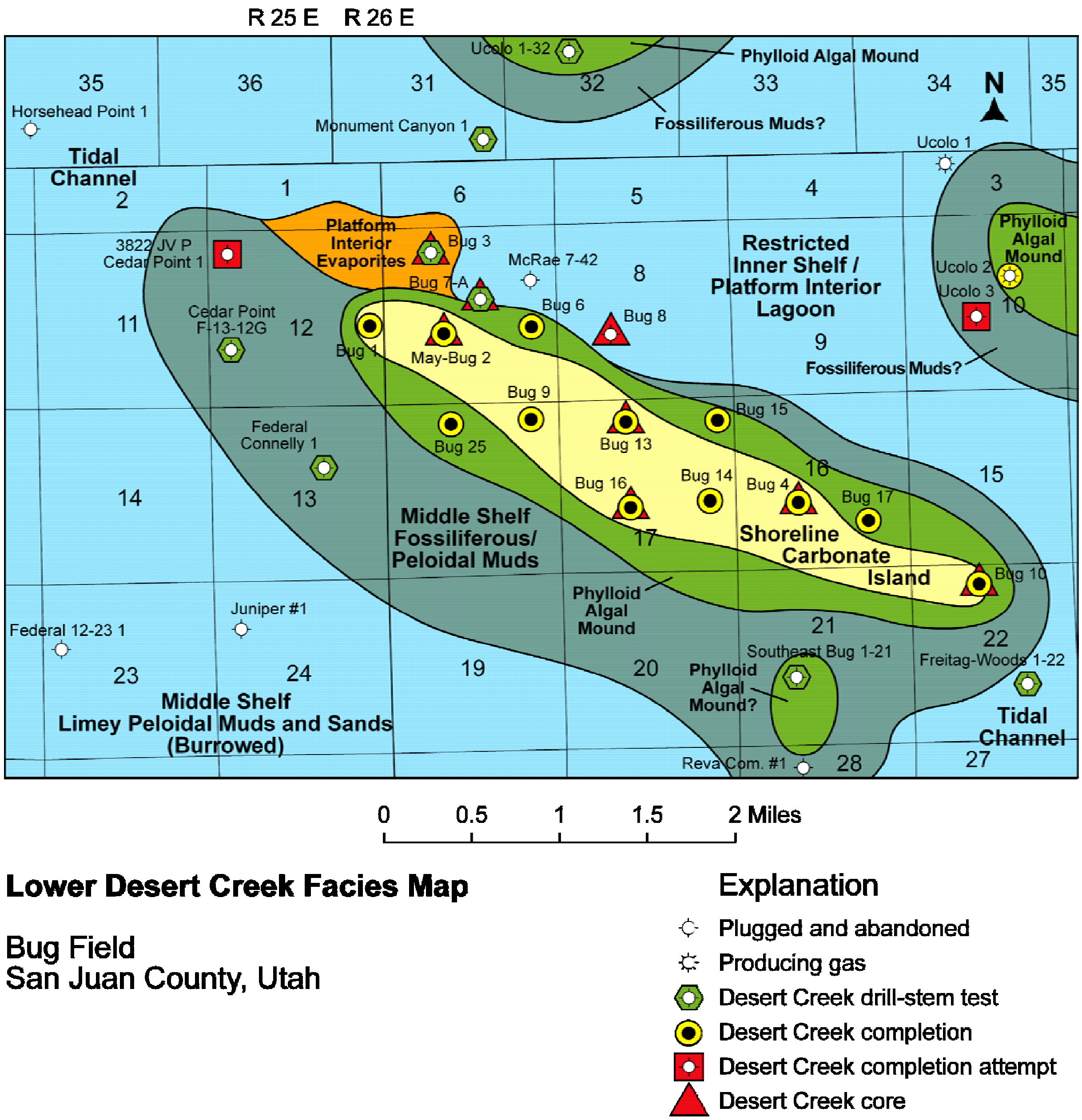



*Figure 12. Lower Desert Creek zone facies map, Bug field, San Juan County, Utah.*

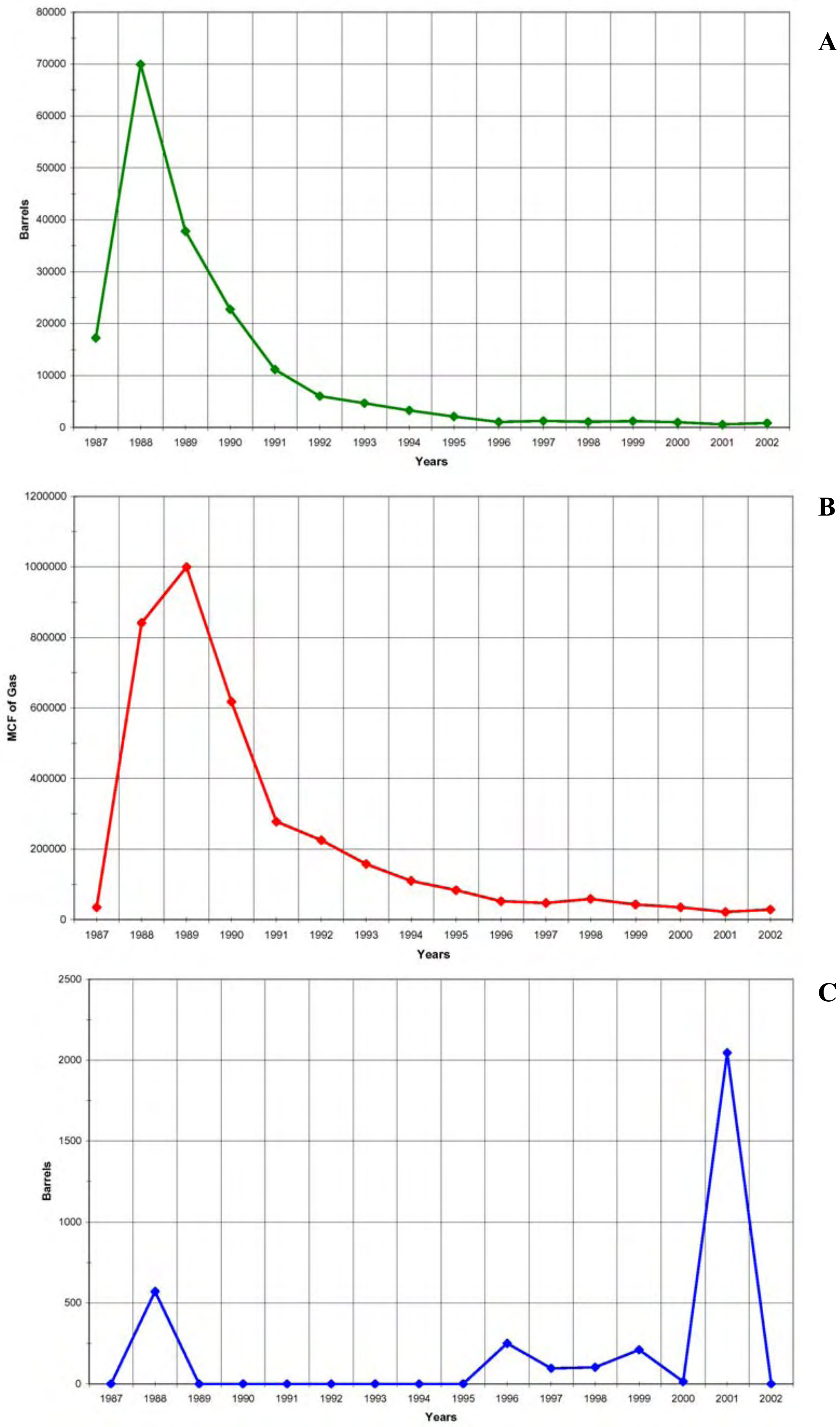



*Figure 13. Historical oil (A), gas (B), and water (C) production for Cherokee field (data source Utah Division of Oil, Gas and Mining).*

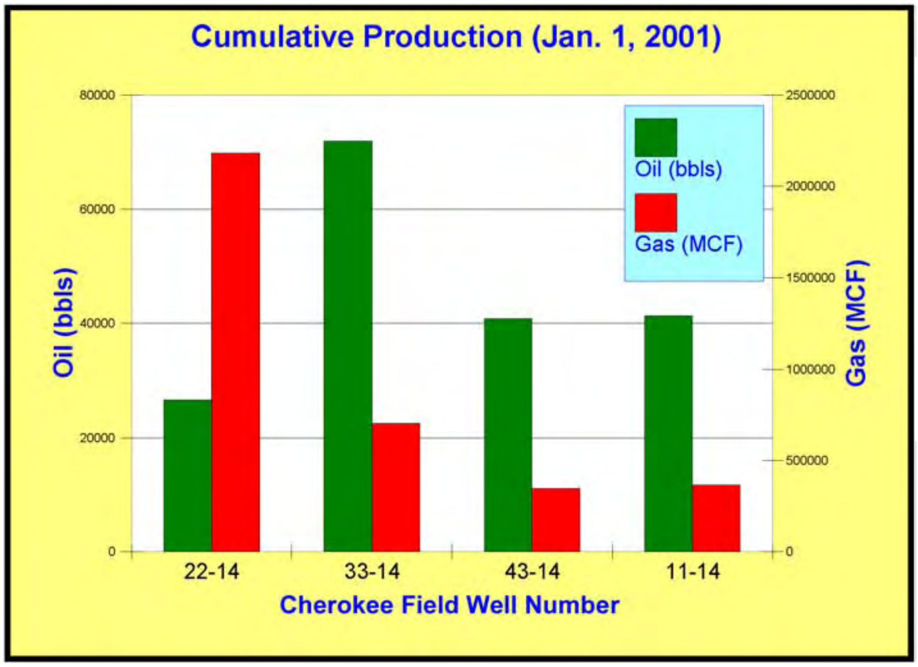



*Figure 14. Cumulative production of oil and gas, from upper Ismay producing wells, in Cherokee field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

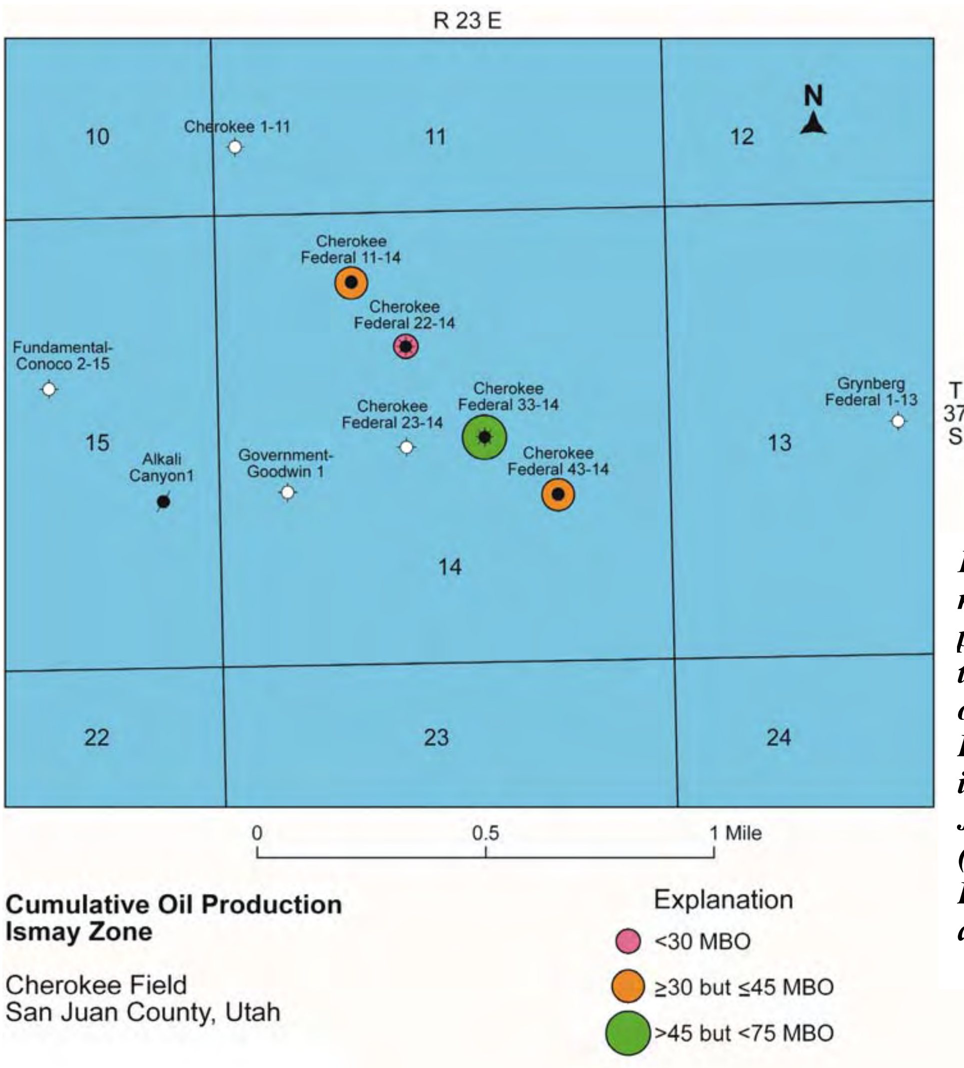



*Figure 15. Bubble map of cumulative production, of oil in thousands of barrels of (MBO), from upper Ismay producing wells in Cherokee field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

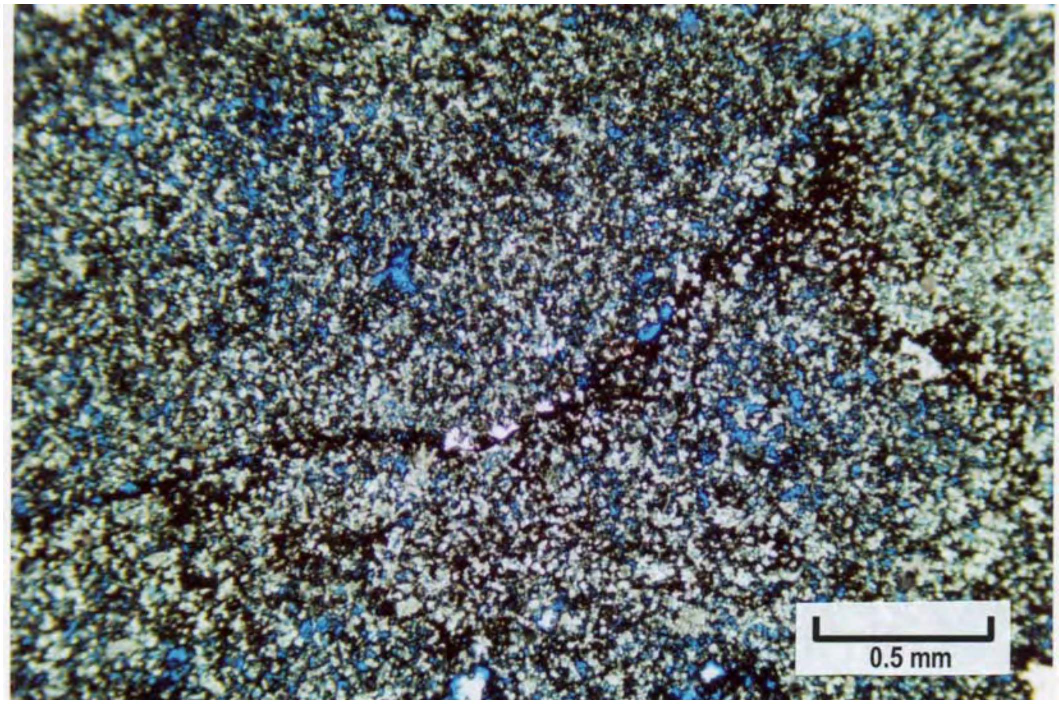



***Figure 16. Photomicrograph (plane light) of a peloidal packstone/grainstone dominated by microporosity (in blue). Cherokee No. 22-14, 5,768.7 feet (1,758.2 m), porosity = 22.9 percent, permeability = 215 millidarcies.***

In Bug field, oil and gas production peaked in 1982. There has been a steady decline in oil and gas production since 1985 and 1989, respectively (figure 17). The largest volumes of oil have been produced from the May Bug 2 and Bug 14 wells (figures 18 and 19). These wells, plus Bug 4 and Bug 9, have each produced over 200,000 barrels of oil. They are all located structurally downdip from the updip porosity pinch out, and in the main part of the lower Desert Creek zone carbonate buildup (figures 11 and 12). These wells penetrated both the phylloid-algal mound and the shoreline carbonate island facies. However, there are other wells that penetrated this same facies combination, such as Bug 16, yet have produced lower volumes of oil. These wells may have encountered fewer microfractures and less micro-box-work porosity (figure 20), a prime diagenetic pore type in this dolomitized reservoir, which is thought to account for the greatest hydrocarbon storage and flow capacity in the field. The lowest volumes of hydrocarbon production are from wells closest to the updip porosity pinch out (Bug 15 and Bug 17) or downdip near the oil/water contact (Bug 25) (figures 11, 18, and 19). These wells penetrated only the phylloid-algal mound facies (figure 12). Bug 13 and Bug 15 are the structurally highest wells in the field and are located near a presumed gas cap, thus their production history shows high GORs.

## ACKNOWLEDGEMENTS

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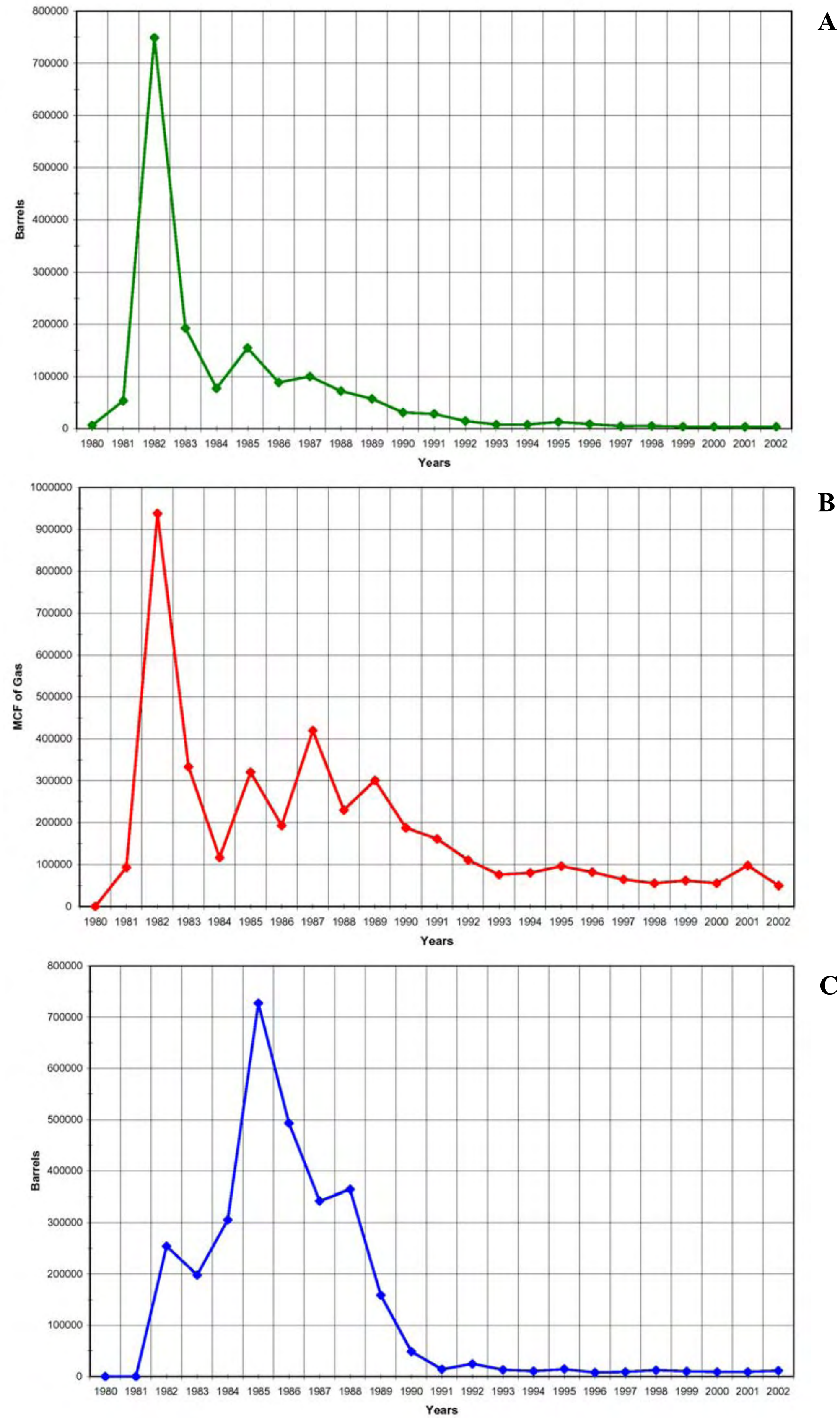


***Figure 17. Historical oil (A), gas (B), and water (C) production for Bug field (data source Utah Division of Oil, Gas and Mining).***

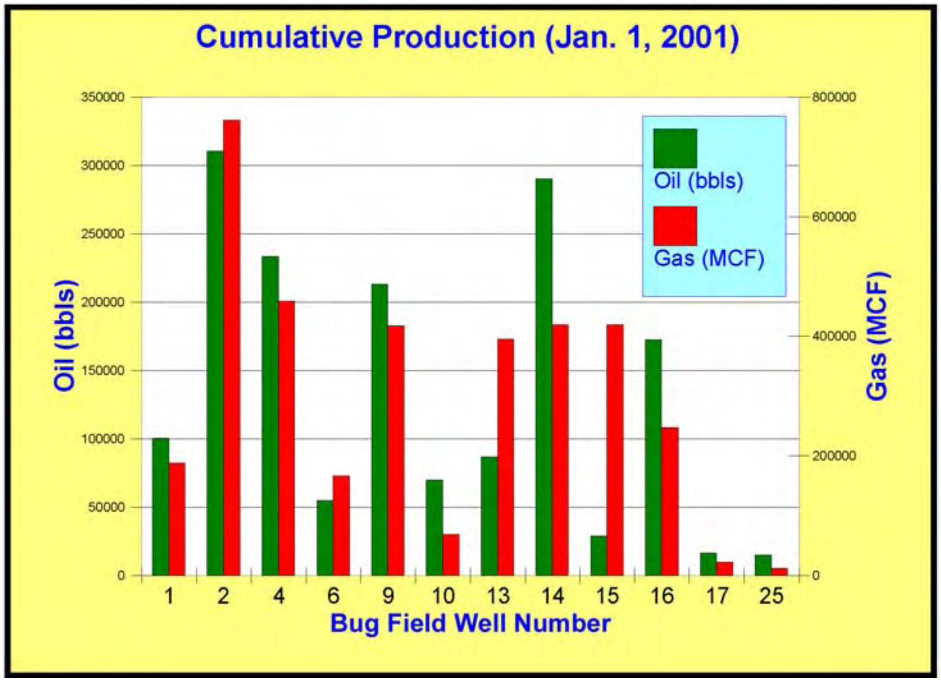


*Figure 18. Cumulative production of oil and gas, from lower Desert Creek producing wells, in Bug field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

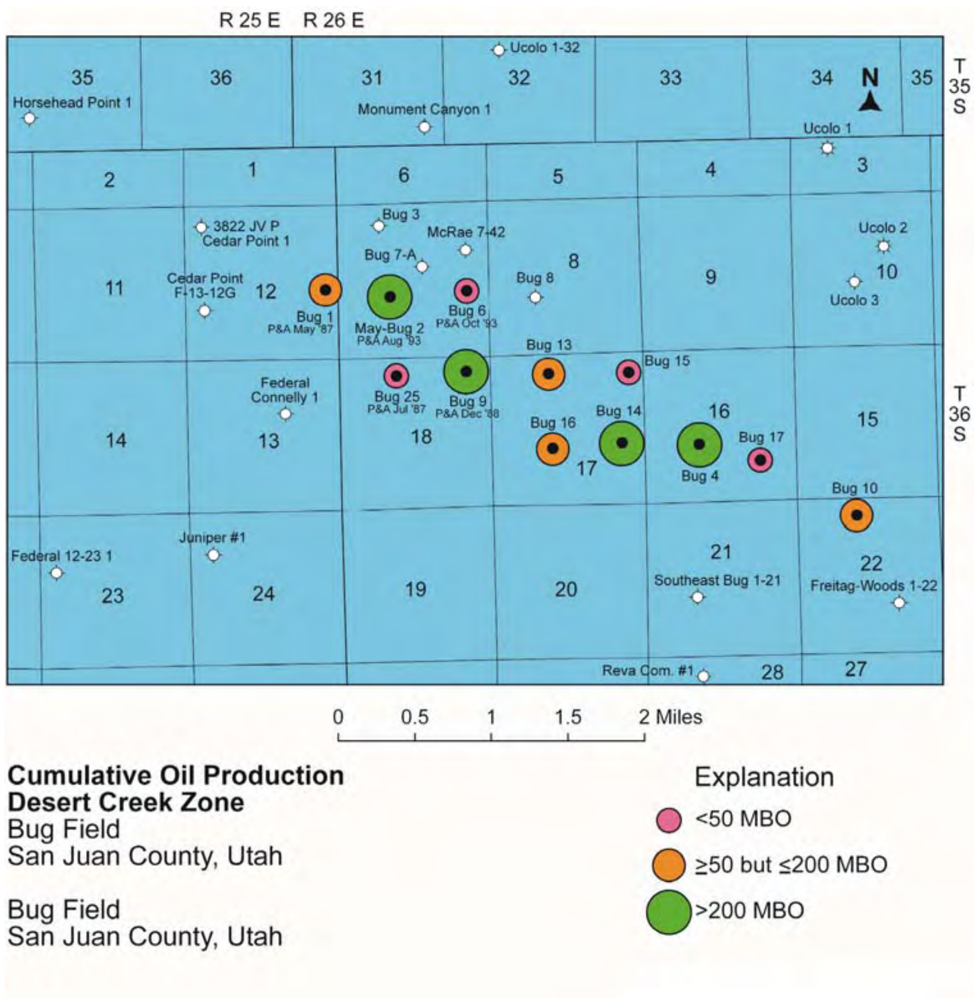


*Figure 19. Bubble map of cumulative production, of oil in thousands of barrels of (MBO), from lower Desert Creek producing wells in Bug field, San Juan County, Utah (data source Utah Division of Oil, Gas and Mining).*

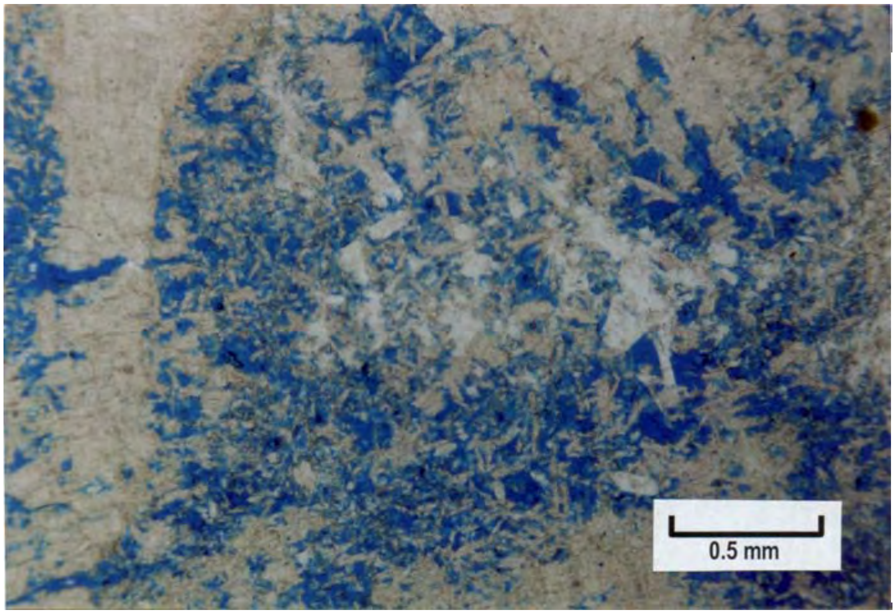


***Figure 20. Photomicrograph (plane light with white card technique [diffused light using a piece of paper on the stage of the microscope]) showing a pattern of patchy dolomite dissolution which includes a "micro-box-work" pattern of pores (in blue). Bug No. 10, 6,327.5 feet (1,928.5 m), porosity = 10.5 percent, permeability = 7.5 millidarcies.***

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